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A fiber optic sensor to measure surface tension

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Abstract : A simple fiber optic sensor based on the coupling of light from one optical fiber to another through a liquid drop is discussed. The drop period measured from the fiber drop trace obtained on a chart recorder, is used to calculate the surface tension of the liquids employed in the experiment.

Keywords : Fiber optic sensor, surface tension

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An instrumental method for the measurement of the physical and chemical properties of various liquids have been developed by McMillan *et al* [1]. The instrument called the fiber drop analyser (FDA) is useful for the measurement of surface tension, viscosity, refractive index, pH and the chemical composition of liquids. In the FDA, light launched from a laser through a source fiber is injected into a liquid drop formed at the tip of a capillary tube. A detector fiber then couples a portion of the injected radiation back to a detector. The detected signal is then displayed on a storage oscilloscope or charted on a chart recorder. The FDA thus produces a signal which varies with time, described as the fiber drop trace (FDT). The FDT consists of various peaks, each of which corresponds to various total internal reflections. The actual form of the trace is very much dependent on the geometry of the optrode. The liquid drop requires a fundamental time to form and separate. This time measured between any two corresponding points on the FDT is referred to as the drop period T. In this paper, we describe the measurement of surface tension of certain liquids using a particular geometry for the FDA.

The surface tension of a liquid is given by $\sigma = dVgF/r$ [2] where the equilibrium drop volume $V = qT$ for an experimental set up with constant volume delivery of q μl / s and for drops with a drop period of T seconds. d is the density of the liquid, g is the acceleration

due to gravity, r is the outer radius of the capillary tube and F is an empirical correction factor given by

$$F = 0.14782 + 0.27896\,X - 0.166\,X^2,$$

where the dimensionless number $X = r/V^{1/3}$ [3]. In the region $0.3 < X < 1.2$, the data are considered most accurate.

The experimental set up (Figure 1) employed in the present investigation consists of a conical reservoir connected to one end of a capillary tube of outer diameter 6 mm. Two multimode silica fibers (200 / 380 μm) are inserted through the capillary tube such that the free ends of the fibers coincide with the tip of the capillary tube. The test liquid taken in the conical reservoir oozes through the capillary tube and drops are formed at its tip. Light from a semiconductor laser with output power 4.25 mW emitting radiations at a wavelength of 670 nm is focussed onto one end of the source fiber using a convex lens of short focal length (f = 5 cm). This light is coupled to the detector fiber after reflections in the liquid drop formed at the capillary end. The coupled light is then fed to a detector – a photomultiplier tube (JETRONICS SO 239) – powered by a high tension voltage from a highly stabilised power supply.

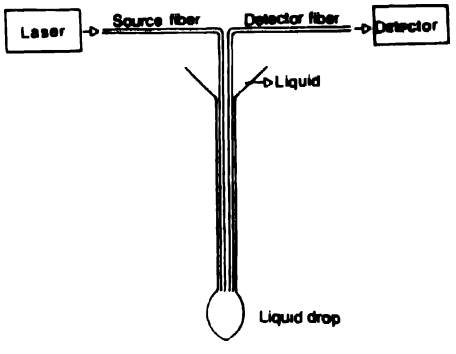

Figure 1. Schematic diagram of the experimental set up.

As the drop size increases, the amount of light gathered after reflections in the drop by the photomultiplier tube (PMT), keeps on changing. These variations in the signal intensity as detected by the PMT is then given to a chart recorder (DIGILOG 2000). The variation of the detected signal with time – the fiber drop trace (FDT) – is recorded for the various test liquids used. The liquids used in the present investigation are a class of viscous liquids like glycerine, castor oil, olive oil and paraffin oil. The output signal detected for castor oil is shown in Figure 2. For every experimental trial, the set up is thoroughly rinsed, taking care not to disturb the alignment of the fibers within the capillary tube.

The outer radius (r) of the capillary tube is measured using a travelling microscope and the drop volume V is noted. The value of the dimensionless number is evaluated to be 0.96. The empirical correction factor F is determined using this value, and is found to be

0.263. Knowing the density d of the liquids used and noting the corresponding drop periods T from the fiber drop trace, the surface tension of the liquids are evaluated and is presented in Table 1.

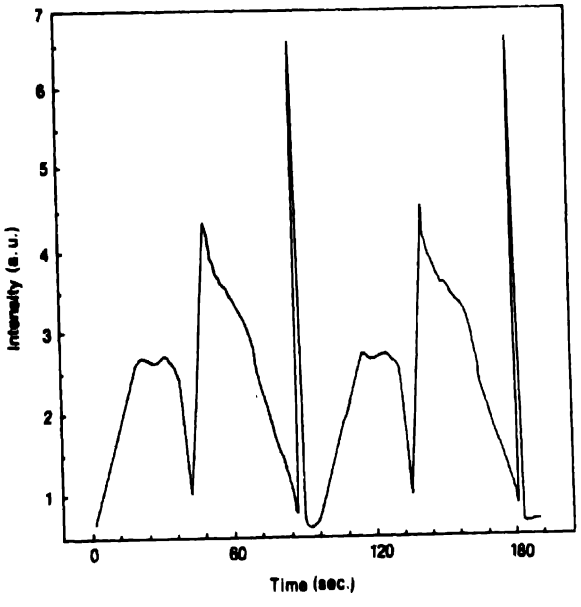

Figure 2. Fiber drop trace of castor oil.

The results reveal that the measured values of surface tension by the present experimental scheme in the case of olive oil, paraffin oil and castor oil agree very well with the standard values. Large deviations (around 25%) from the literature value is observed in

Table 1. Surface tension of the liquids

Liquid	Flow rate q (μl/s)	Time from FDT T (sec)	Density of the liquid d (kgm^{-3})	Standard surface tension (10^{-3} N/m)	Calculated surface tension (10^{-3} N/m)
Olive Oil	4.96	9.60	920	32	32.55
Castor Oil	0.51	93 60	969	33	34.39
Paraffin oil	2.76	17.30	800	26	28 41
Glycerine	1.60	29 80	1260	63	44.67

the case of glycerine [4]. This deviation suggests that the present experimental scheme can work at its best only when the surface tension of the liquid being measured falls within a certain range. The exact range of its applicability can be ascertained only by carrying out measurements on some more liquids with large values of surface tension.

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